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14. ABSTRACT
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The body of the paper focuses on recent developments at the Air Force Research Laboratory (AFRL), Tyndall AFB, Florida, which improve the performance and usefulness of matting systems. The paper focuses on the pioneering efforts of AFRL in the use of Elastomer Sprayed Coating (ESC) in three major Rapid Runway Repair (RRR) areas: (1) unreinforced ESC as a FOD cover; (2) ESC with wire mesh reinforcement to create an improved FOD cover; and (3) ESC as a means of expediently anchoring FFMs. In addition, ongoing research at AFRL for structural mat improvements is briefly discussed, including interior AM-2 mat repair techniques and a revolutionary lightweight replacement for AM-2 matting.

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Recent Advances in Matting Technology for Military Runways

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Abstract

The paper first gives a historical perspective to military usage of mats on runways, taxiways, aprons, and parking areas. Common matting systems are discussed which fall into two general categories, structural matting and FOD covers. Structural matting, such as AM-2, is used to increase the runway's structural support when the surface is otherwise inadequate. FOD (i.e., foreign object damage) covers, such as folded fiberglass mats (FFMs), are used on surfaces that are adequate structurally, but have a high incidence of FOD.

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Background *(Runway Repair Operations, 1997; Rapid Runway Repair, 1999)*

Introduction. The Air Force flies and fights from its air bases. However, it is at the air base that air power is most vulnerable. They can be the most immediate and lucrative targets for an adversary. After all, it is far more effective to destroy aircraft on the ground than to hunt them in the air. In future conflicts, one of the military engineer's primary wartime missions will likely be the repair of airfield pavement damage.

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World War II. American military leaders of World War II recognized the vital need for airfields to support operations in all theaters of operation. Many times this meant repairing enemy airfields or constructing new ones as quickly and close to the front as possible. To provide this level of support, Aviation Engineers experimented with several different types of matting materials. Some never proved feasible. For example, the attempt to construct a runway with wooden "2 x 4" landing mats (i.e., mats made from planks with nominal size of 5 cm x 10 cm) was too costly and labor intensive. However, the engineers did develop several types of materials enabling them to provide expedient runways in just days (or even hours). The three primary matting materials used during World War II were: Pierced Steel Planking (PSP), Hessian Matting, and Square Mesh Track (SMT).

Figure 1. Pierced Steel Planking (PSP) being installed at night by men of the IX Engineer Command at an Air Force Base in Germany (circa 1945).

Pierced Steel Planking (PSP), also known as Marston Matting, was initially tested at Langley Field, Virginia, in 1940 and was in wide use even through the Korean War. Installation of PSP is shown in Figure 1. PSP proved to be very versatile. It was comparatively light, yet fairly rigid and very transportable. The simple hook design on the plank edges made assembly a fast and relatively easy undertaking, and minor replacement repairs usually ended up requiring only two men to accomplish. When major repairs were necessary, large sections of planking could actually be rolled up and removed and replaced as appropriate. A major drawback that eventually brought about its replacement was the development of drainage problems. The holes in the planking served to reduce weight but also resulted in an undesirable "pumping" action that caused rapid base course failures in wet climates (such as Southeast Asia). By the end of World War II, enough PSP had been manufactured to construct nearly a thousand 46 m x 1.5 km (150 ft x 5,000 ft) runways (as shown in Figure 1).

Hessian Matting, also known as Prefabricated Hessian Surfacing, was originally developed by the Canadian Army engineers. It was composed of bitumen impregnated Hessian cloth (a type of burlap) and was used primarily as a waterproof cover for the runway surface. With Hessian Matting, engineers could construct an acceptable runway surface in a very short period. However, frequent maintenance requirements in aircraft braking and turning areas coupled with its generally short lifespan were the product's primary shortfalls. In addition, the material could not be placed when the grade was wet.

Square Mesh Track (SMT) was specifically developed as an expedient temporary runway surfacing material in support of the invasion of Europe. SMT runways were limited to light and medium weight aircraft. During the invasion period, engineers constructed nine SMT airfields. As a primary runway surfacing material, SMT received mixed reviews. It was light and highly mobile, but did not hold up well under heavy use. However, during the latter part of World War II, a common practice was to employ Hessian Matting in combination with SMT and PSP. This "sandwich" product provided

a much more durable runway platform; but the process was labor intensive, so its use was limited to areas where enemy air attack was least probable.

Post World War II. With the onset of the "Cold War" shortly after World War II and the permanent posturing of Air Force units at overseas locations, construction of expedient airfields became a reality. Furthermore, with the addition of sophisticated fighter aircraft to the inventory, "smoothness" of runway surfaces became an absolute must. No longer was there great interest in the expeditionary runway technology of the past. The day of earthen runways and expedient surfaces was gone. In its place was a burning need for expedient airfield repair technology--rapid runway repair (RRR). This was driven by the relatively close proximity of the potential enemy to our permanent platforms. AM-2 aluminum matting, precast concrete slabs, and the folded fiberglass mat (FFM) techniques were developed to meet that need.

AM-2 matting became part of the Air Force inventory in 1965 and was primarily used for construction of expedient runways, parking aprons, and taxiways. The Tuy Hoa Air Base runway (see Figure 2) and the extensive aircraft parking ramp at Phu Cat Air Base, both in the Republic of South Vietnam, were examples of AM-2 matting use for expedient construction. In the summer of 1975, the concept of using AM-2 material for bomb crater repairs was first tested at Air Force Research Laboratory facilities on Tyndall Air Force Base. From these tests, AM-2 rapid runway repair (RRR) procedures were developed that are still in use today (see Figure 3a). Among the system's many strong points are portability and durability. Its major drawbacks include labor intensity and the transitional bounce that was created between the 4 cm (1½") mat and the adjacent hard surface.

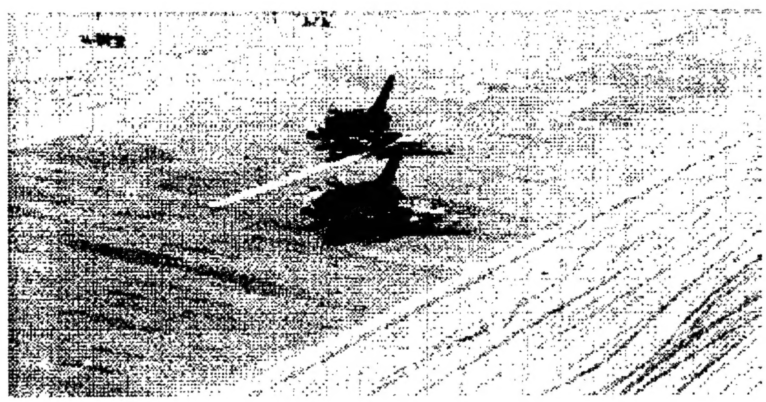
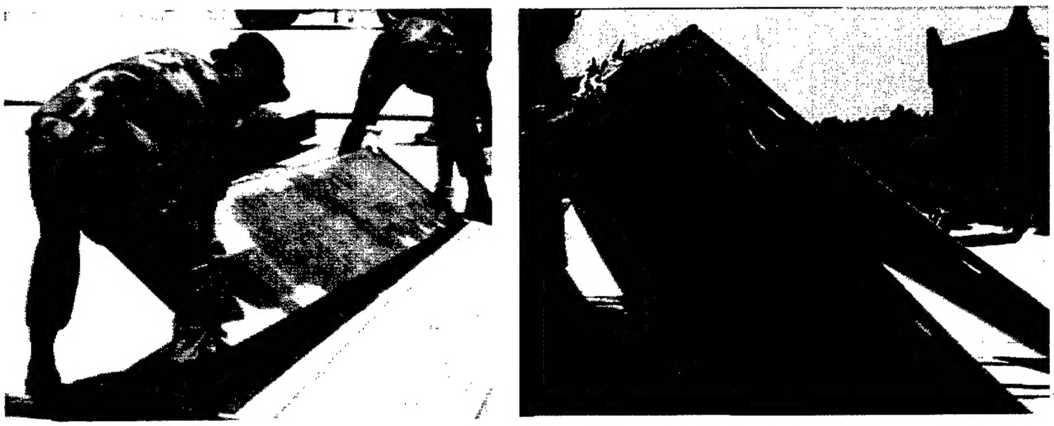


Figure 2. Fighters land on a 2.7-km (9,000-ft) runway constructed of AM-2 matting at Tuy Hoa Air Base, Republic of South Vietnam (circa 1968)

In the early 1980s, Headquarters-United States Air Forces in Europe (HQ USAFE) adopted the precast concrete slab repair technique as its primary RRR method. The procedure was already being used (to a limited extent) by the West German Air Force. The ample stocks of AM-2 matting postured throughout the command were designated as a backup system for the precast slab method or for use in taxiway repairs. At that time, the concrete slab repair system was the only fielded RRR technique that could, when correctly installed, provide a truly flush crater repair – a most desirable feature. However, the system did have two notable drawbacks: it was not very portable and was heavily dependent on specialized equipment. In October 1994, HQ USAFE officially discontinued use of the precast concrete slab repair system, and replaced it with the folded fiberglass matting (FFM) repair method as their primary RRR procedure.

As early as the 1970s, the Air Force Engineering and Services Center (AFESC),[4] was working diligently at developing a synthetic matting system that would provide portability without the transitional roughness problems associated with AM-2 matting. Initial versions of their efforts were fielded in the Pacific Air Forces (PACAF) theater in August 1984, and were called Polyurethane Fiberglass Mats (PFMs). Unfortunately, these early PFM products were not well received, mainly because of the storage and transport problems presented by their sheer bulk (PFMs were 15 m x 18 m (50 ft x 60 ft) in size, not foldable, and weighed approximately 680 kg (1,500 lb)).

Still, research continued on fiberglass matting, and in February 1992, the folded fiberglass mat (FFM) system was completed. FFM is still employed Air Force-wide as the primary RRR method (see Figure 3b). Although the most functional RRR system yet accepted for use, FFMs have several weaknesses (see next section for discussion).



(a) AM-2 mat (short panel) (b) Folded fiberglass mat (FFM)

Figure 3. RRR mats currently approved for Air Force use

The Future of Mats for RRR. In current and future hostilities, the United States Air Force will, as in the past, play a decisive role in defeating the aggressor. The flexibility, massive firepower, and speed of employment of our air forces are capabilities needed to win any conflict. The overwhelming success enjoyed by the Air Force from World War II through the Persian Gulf War amply demonstrated these features. To preserve these characteristics, however, we must maintain the relatively uninterrupted operation of our forward-based airfields through all stages of a conflict.

Obviously, the scope of airfield operating surface repair requirements will vary proportionally to the intensity of the attack. It could range from minor pavement disruption with minimal interference to aircraft operations, all the way up to major airfield damage accompanied by complete shutdown of aircraft launch and recovery activity. It is the latter possibility that we must be prepared to handle swiftly and correctly. We should expect major airfield damage to include multiple bomb craters and numerous spall fields. Stated simply, the RRR mission is to overcome these multiple problems and provide an accessible and functional minimum airfield operating surface. Airfield matting and mat systems will continue to be a key component of RRR for the foreseeable future.

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[4] In the early '90s, AFESC was reorganized. The civil engineering support function became the Air Force Civil Engineer Support Agency (AFCESA), headquartered and located at Tyndall AFB, FL. The civil engineering research and development function was transferred to the Air Force Research Laboratory (AFRL), Wright-Patterson AFB, OH; but the AFRL pavements research and development facilities (AFRL/MLQD) have continued to be physically located at Tyndall AFB, FL.

Problems / Solutions with Currently-Approved Mat Systems

Problems with FFMs. There are also several problems with the current FOD cover used by the Air Force (i.e., folded fiberglass mat (FFM)): (1) the shear strength is not sufficient to keep a deformation "wave" from forming in front of some moving aircraft wheels; (2) the mats are flexible, and premature rutting in the repaired crater is a problem; (3) although thin compared to AM-2, thickness of FFMs is still a problem for some aircraft; (4) the installation process is complicated and labor intensive; (5) mobilization and re-mobilization of the installation equipment is a problem; (6) the repair kit requires a large storage area; (7) the elastomer hinges that allow folding may be damaged with heavy usage; and (8) bolts and other anchoring components become potential FOD.

Problems with AM-2 mats. There are several problems with the current structural mats used by the Air Force (i.e., AM-2 mats). In general, these problems relate to the size and weight of the panels: (1) the full-size individual panels are large in size, 0.6 m x 3.7 m (2' x 12'), making them unwieldy and sometimes dangerous to handle (half-panels are 1.8 m (6') long, as shown in Figure 3a); (2) the individual panels are heavy, again making them unwieldy and sometimes dangerous to handle; (3) the installation process is labor intensive; (4) the thickness of 4 cm (1½") causes problems for some aircraft, particularly fighters, even with transition ramps; (5) interior repair of a damaged panel requires a significant effort in both labor and heavy equipment, since the mats must be placed sequentially; and (6) the mats require significant storage area.

Recent AFRL Solutions. As can be seen in the above lists, the problems of structural mats and FOD covers are generally quite different (although there is a small amount of overlap). The Air Force Research Laboratory (AFRL) is continuing to research better matting techniques, to overcome the shortcomings in both types of RRR mats. Recent research in improved FOD covers has focused on the use of Elastomer Sprayed Coating (ESC), which is discussed at length in the next section. Recent research to improve structural mats has included both improved repair techniques and the development of lightweight replacement mats. This research is ongoing and is discussed only in summary fashion in a subsequent section.

Use of Elastomer Sprayed Coating (ESC) for RRR

Introduction to ESC. Elastomer Sprayed Coating (ESC) is a two-component, spray-in-place thermoplastic polyurea system. The system is flexible, but is composed of 100% solids (0% volatile organic compounds (VOCs)). It is designed for processing through high-pressure impingement-mix polyurethane dispensing equipment. ESC is a multi-purpose material that is fast curing and has a textured surface. It exhibits excellent adhesion to most materials and is generally suitable as a protective layer/liner for most structural surfaces, as it resists both abrasion and impact.

Delivery Equipment for ESC. Figure 4 shows a schematic of the ESC delivery system. There are two barrels, one with resin and one with hardener (i.e., a catalyst). Material from the two barrels are pumped, mixed, and sprayed with the assistance of compressed air which enters through the manifold. The hose is heated to prevent premature setting.

Test Cases for ESC. Three different test cases were examined : (1) Unreinforced ESC used as a FOD cover for a crater repair; (2) Wire-mesh reinforced ESC used as a FOD cover for a crater repair; and (3) ESC used to anchor FFM. In all test cases, the craters were prepared in accordance with standard Air Force procedures (up until the point where the FOD cover would normally be applied) *(Rapid Runway Repair, 1999)*.

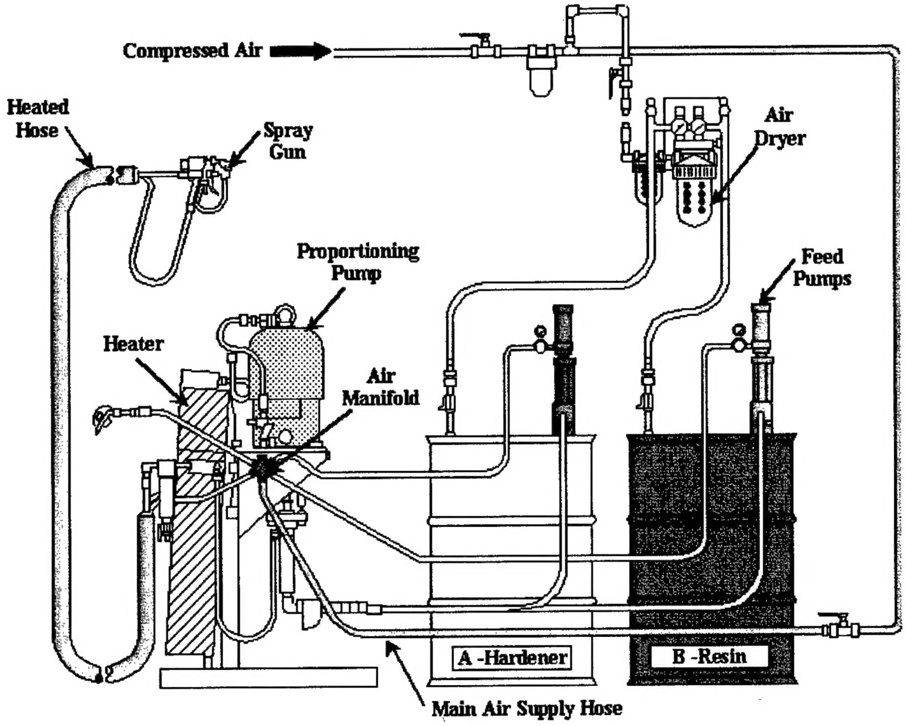


Figure 4. Schematic of Elastomer Sprayed Coating (ESC) Equipment

Load Testing. All three ESC cases were tested with a load cart which simulates the front wheel of an F-15 fighter, as shown in Figure 5g. The front wheel of the F-15 remains the critical single wheel load (i.e., the single wheel load which has the highest runway damage factor) for both the United States Air Force (USAF) and the Israeli Air Force (IAF), due to the combination of heavy weight and high tire pressure *(Holliway and Millard, 1990)*. The load cart shown in Figure 5g, and used in the testing, was configured with a single wheel load of 15,000 kg (33 kips) and tire pressure of 2.4 MPa (350 psi).

Test Case 1 – Unreinforced ESC as a FOD Cover

Test Case 1 Procedure. Figure 5 illustrates the entire procedure for Test Case 1, including the installation of the unreinforced ESC FOD cover, and testing to determine the capability of the ESC FOD cover to withstand loading by the F-15 aircraft. Figure 5a shows a test crater which has been repaired by standard Air Force procedures *(Rapid Runway Repair, 1999)*, but just before a FOD cover would normally be applied. Figures 5b and 5c show special preparation needed to assure a good bond between the existing crater shoulder and the ESC, i.e., cleaning the shoulder with compressed air and then applying primer. Figure 5d shows the AFRL ESC equipment previously shown in schematic form in Figure 4. The ESC equipment is trailer mounted for easier use. Figures 5e and 5f show spraying the ESC to a thickness of 6 mm (¼"), up to and including the crater shoulders, to create a monolithic, anchored FOD cover. Figure 5g shows the F-15 load cart (configured as previously discussed). Figure 5h shows the unreinforced ESC FOD cover after 150 passes of the F-15 load cart.

Test Case 1 Results. The unreinforced ESC had an acceptable amount of vertical deflection after 150 passes with the F-15 load cart. However, there was a significant "wave" in front of the load cart wheel, indicating poor resistance to horizontal (i.e.,

(a) Crater structural repair (base)

(b) Air-cleaning repair shoulders

(c) Priming repair shoulders

(d) AFRL ESC equipment

(e) Spraying to 6-mm (¼") thickness

(f) Resulting ESC FOD cover

(g) F-15 load cart

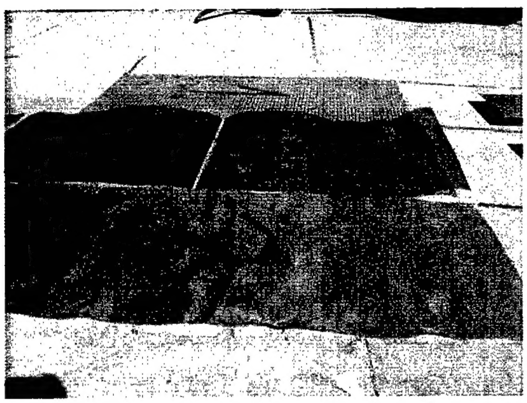
(h) After 150 load cart passes

Figure 5. Crater repair using unreinforced Elastomer Sprayed Coating (ESC)

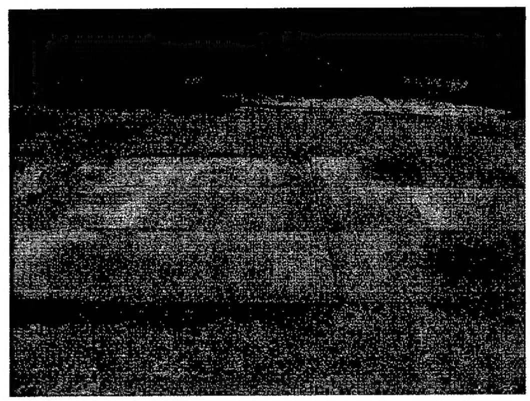
shear) loads. These results indicated that the unreinforced ESC FOD cover would not fail under the expected vertical load, but needed reinforcement to withstand horizontal loads.

Test Case 2 – Wire-Reinforced ESC as a FOD Cover

Test Case 2 Procedure. This test case actually consisted of four sub-cases, where each sub-case used a different reinforcing mesh. Samples of the different meshes are shown in Figure 6a. In all four sub-cases (and as previously described for Test Case 1), standard Air Force procedures were used to repair the crater up to the point where a FOD cover would normally be applied *(Rapid Runway Repair, 1999)*. The results reported herein for Test Case 2 are only for the mesh which worked best, i.e., the 13-mm (½") aluminum mesh. Figure 6b shows the 13-mm (½") aluminum mesh after being sprayed with a "tack coat" of ESC. The reinforced ESC FOD cover was sprayed to a thickness of 6-mm (¼") and anchored to the crater shoulder with ESC, then loaded with 150 passes of the F-15 load cart.



(a) Four meshes were tested



(b) ESC on 13 mm (½") aluminum mesh

Figure 6. Crater repair using wire-reinforced Elastomer Sprayed Coating (ESC)

Test Case 2 Results. The performance of the reinforced ESC as a FOD cover was very good. After 150 passes of the F-15 load cart, there was no significant vertical deflection, and no "wave" in front of the load cart wheel. That is, the reinforced ESC was able to withstand the horizontal loads (as well as the vertical loads).

Test Case 3 – ESC as an Anchor System for FFM

Test Case 3 Procedure. The third case examined did not use ESC as a FOD cover, but rather as an expedient anchor system for folded fiberglass mats (FFMs). In this case a standard Air Force FFM was used, except that the size of the FFM was cut to just larger than the crater. As with the previous Test Cases, the crater was prepared in accordance with standard Air Force procedures up to the point of applying a FOD cover *(Rapid Runway Repair, 1999)*. At that point, the "cut down" FFM was placed to the prepared crater (as shown in Figure 7a). Then, ESC was sprayed on the edges of the FFM and across to the crater shoulder, to a thickness of 6 mm (¼") (as shown in Figure 7b). The total width of the ESC layer was 0.6 m (2'), with 0.3 m (1') on the FFM and 0.3 m (1') on the crater shoulder. No other anchor was used to hold the FFM in place. Subsequently, the ESC-anchored FFM was trafficked with 150 passes of the F-15 load cart, and the results were compared to a standard FFM repair system.

Test Case 3 Results. FFM performed better under the prescribed test loading than a

(a) Unanchored FFM FOD cover (b) ESC used to anchor FFM

Figure 7. ESC used to anchor folded fiberglass mat (FFM)

standard FFM system. With the smaller sections, anchored by ESC, the FFM had dramatically reduced "wave" size (i.e., the reaction to horizontal loading) in front of the moving load cart wheel, compared to a standard FFM repair. Both the standard FFM system and the ESC-anchored FFM system had relatively small deflections under the vertical load.

Summary Results. Summary results are shown in Table 1, below:

Test Number	Test Description	Vertical Performance	Horizontal Performance
1	Unreinforced Elastomer Sprayed Coating (ESC) as a FOD Cover	Good	Poor
2	Aluminum Wire-Reinforced Elastomer Sprayed Coating (ESC) as a FOD Cover	Good	Good
3	Elastomer Sprayed Coating (ESC) as Expedient Anchor for Folded Fiberglass Mat (FFM)	Good	Good

Table 1. Summary of Results

ESC Lessons Learned. This testing program pointed out several distinct advantages of using ESC as a material for RRR (in addition to its ability to handle vertical and horizontal wheel loads). The most obvious advantage is the speed with which the FOD cover can be installed, since the ESC acts as anchor (as well as FOD cover). Almost as obvious is the sealed repair created, which completely eliminates FOD from the repair so long as the ESC remains intact and bonded to the crater shoulder. Also, the ESC layer of 6 mm (¼-in) thick (especially when "feathered" at the edges) does not pose a difficulty for current aircraft gears. Finally, from a construction point of view, the ESC equipment is easier to mobilize, and requires less storage space.

Even with the advantages listed above, the ESC method is not without problems. For example, the surfaces must be prepared carefully to insure proper bonding. The spray anchoring, while expedient, is decidedly temporary (i.e., the ESC eventually peels off the crater shoulder). Also, while the ESC equipment is easily stored, it does require

regular maintenance. Finally, the time for curing is very dependent on ambient conditions.

AFRL Research on Structural Mats

Interior Repair of AM-2 Matting. Research is ongoing at AFRL on the problem of interior repair of AM-2 matting. Although methods have previously been developed which can be used, these methods generally require specialized expertise/equipment *(see, e.g., Lindbergh and Currin, 1971)*. A method is being developed at AFRL which will allow an interior repair to be performed expediently with a minimum of labor, equipment, and training. In summary, this method consists of: (1) using handheld saws to cut an internal hole in the AM-2, where the hole size is determined by a simple formula (based on the number of replacement panels); (2) inserting a number of specially designed aluminum braces to form a type of "pocket" to hold the replacement AM-2 panels; (3) placing full-size AM-2 panels into the "pocket"; and (4) completing the repair with specially designed aluminum cover plates and lag bolts.

Lightweight AM-2 Replacement. AFRL is currently researching a revolutionary composite mat to replace AM-2 matting. The composite mat will weigh approximately one-half as much per unit area as AM-2, with approximately the same strength as AM-2. This addresses the AM-2 matting problem of heavy transport aircraft "maxing out" on weight rather than volume. By reducing the average weight density, even with the same exterior dimensions, more panels can be moved in each transport shipment. Two different composite mat configurations are being readied for a full-scale test, which could be completed as early as the fall of 2002.

Conclusions.

- Elastomer Sprayed Coating (ESC) is a viable alternative for expedient FOD covers, particularly when reinforced with aluminum wire.
- Elastomer Sprayed Coating (ESC) is a viable alternative for expedient anchoring of Folded Fiberglass Mats (FFMs).
- AFRL is currently pursuing improvements for structural matting which will, when completed, greatly improve our Rapid Runway Repair (RRR) capability.

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